



Designing and Managing for Space Radiation Effects on Devices

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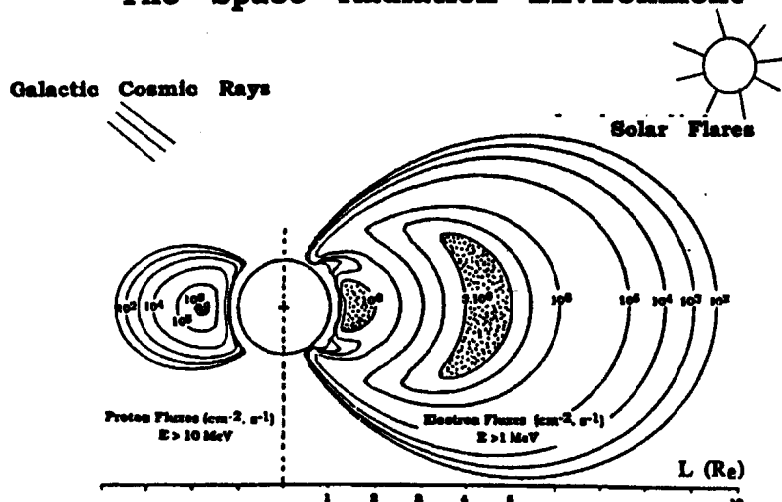
- ☐ Michele M. Gates
- ☐ Radiation Effects and Analysis Section



Today's Topics:

- ☐ Review of Space Radiation Environment and Electronics
- ☐ Radiation Management - A systems engineering perspective
- ☐ Mission Requirements - What you need and why
- ☐ Specifying Parts for Single Event Effects
- ☐ Procuring Parts - Caveat Emptor!
- ☐ Ground Radiation Tests
- ☐ Living with Radiation - methods of dealing with the problem parts
- ☐ Miscellaneous

The Space Radiation Environment



Two Main Effects on Electronics

Total Dose (TD)

- Cumulative long term effect due to protons and electrons
- May cause threshold shifts, leakage current, timing skew, functional failures, et al.
- May be mitigated by shielding

Single Event Effects (SEE)

- Event caused by a single energetic particle such as a cosmic ray or proton
- May cause soft or hard errors such as bit flips in memory or register, transients in I/O circuitry or destructive conditions such as burnout or latchup
- May NOT be mitigated by shielding



Why worry? - Samples of Radiation-induced Spacecraft Anomalies

- ☐ Single Event Upsets (SEUs) have been verified in the space radiation environment
 - ☐ SMM, TDRS-1, HST, Magellan, NOAA-10, Mars Observer, et al...
 - ☐ Failures due to SEEs (either SEUs or Single Event Latchup) 2 examples
 - ☐ GPS was uncontrollable for two months following 4/83 solar flare
 - ☐ ESA ERS-1 instrument failure due to SEL (first proton-induced SEL verified in space)
 - ☐ Total dose degradation of solar arrays during solar flares has been well-documented
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Emerging Commercial Technologies in the Space Radiation Environment

- ☐ Provide a "Better, Faster, Cheaper" spacecraft
 - Higher density with decreased device geometry
 - Increased performance
 - Easier path using COTS development tools
 - Reduced integration time
 - Decreased lead times versus RH parts procurement
 - ☐ The Space Radiation Environment may be harsh on these devices
 - Higher SEE sensitivity
 - Lower TD tolerance
 - ☐ System design may be used to compensate, but devices require testing in order to determine viability
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Mission Requirements - What you need and why

- ☐ Specifying the Space Radiation Environment
 - ☐ Total Ionizing Dose (TID) - usually a dose depth curve
 - ☐ Cosmic Ray Spectra (or LET spectra)
 - ☐ Trapped Proton and Electron Curves
 - ☐ Solar flare (or solar proton event) spectra for solar max
 - ☐ For solar arrays: 1 MeV equivalents of proton and electron spectras
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TID

- ☐ A dose depth curve shows TID versus the amount of shielding
 - ☐ Note that there are three different shielding models used and they are vastly different
 - ☐ Center of Al sphere is the most conservative, Finite Al slab is the least conservative, semi-infinite slab is between the two
 - ☐ There are many components that contribute to TID: protons, electrons, Bremsstrahlung, solar flares, etc ...
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A note to Project Managers - specifying one TID number for box components

- ☐ EXPLICITTE SAFETY MARGINS are NOT included in traditional environmental studies
 - ☐ A rule of thumb is to either use a nominal shielding density (70-140 mills) and the Center of Al spheres dose at that shielding or place a factor of 3 to 10 on the TID from the finite slab curve. This is not to be used as specification, only as a rough approximation.
 - ☐ Underspecifying can lead to mission failure, overspecifying may become a cost and schedule driver.
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Cosmic Ray (or LET) Spectra

- ☐ These are the "free space" particles of galactic or solar origin (earth's magnetic field provides an effective shield)
 - ☐ Integral LET spectra is given for flux (#/particles per day) versus LET (energy lost/deposited as an ion passes through a medium)
 - ☐ Used for SEE analysis (i.e., how many particles can cause an SEE based on device's sensitivity)
 - ☐ LET is usually discussed in MeV/(mg/cm²)
 - ☐ Cosmic rays are severely attenuated by the earth's magnetic field (geomagnetic cutoff).
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Trapped Proton and Electron Spectra

- ☐ These are the particles trapped within the earth's magnetic fields
 - ☐ Used for TID and SEE analyses
 - ☐ Given in integral flux per day or by mission fluence versus particle energy
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Solar flare spectra

- ☐ Provides a confidence level for solar proton events during solar max
 - ☐ A conservative assumption is one AL solar flare per year
 - ☐ Solar flares are severely attenuated by earth's magnetic field, but may cause enhancements (ie, increased particles) in the trapped proton belts for some time period post-flare
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Other things to consider for orbits

- ☐ LEOs see mostly trapped particles
 - ☐ GEOs see mostly free space particles and solar flares
 - ☐ Polar orbits (EOS, SAMPEX) see both
 - ☐ Items such as "flux-free" time periods may be of use in designing systems, especially if there is an instrument sensitivity to radiation-induced background noise (such as in CCDs)
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Problem: Why different groups make different radiation predictions

- ☐ Different input models (solar flare, trapped particles, cosmic ray, etc...)
 - ☐ Different magnetic field models
 - ☐ Different assumptions on "weather" conditions
 - ☐ Different components in model
 - ☐ Time period used: Max or Min
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Bottom line

- ☐ It pays to have a qualified party prepare the radiation environment for a spacecraft (GSFC Radiation Physics Office - E.G. Stassinopoulos)
 - ☐ Interpretation is not straightforward. Help is available through Radiation Effects and Analysis Section (735.1) and/or Stass
 - ☐ Do NOT use tools such as ENVIRONET as anything more than a learning tool. A tool's result is only as good as its user input. Knowledge in the wrong hands can be dangerous.
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Procuring parts for the space radiation environment

- ☐ Both TID and SEE specifications should be included
 - ☐ TID should be given in N krad(Si) as a minimum hardness. N is mission specific.
 - ☐ SEE is not as simple. What follows is a DRAFT generic specification.
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Picking parts for radiation reasons: Pay Attention!

- ☐ Golden rule: Never trust a vendor (especially their salespeople)
 - ☐ Digital: CMOS/SOS is hard! Otherwise, there are few generalities. Bipolar does not equal rad hard (necessarily).
 - ☐ Goddard PPL does NOT convey that a part that is listed is rad hard! This is a problem.
 - ☐ All parts need to be characterized for the radiation environment or be guaranteed by the vendor with Code 300 approval
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General SEU Info and Parts

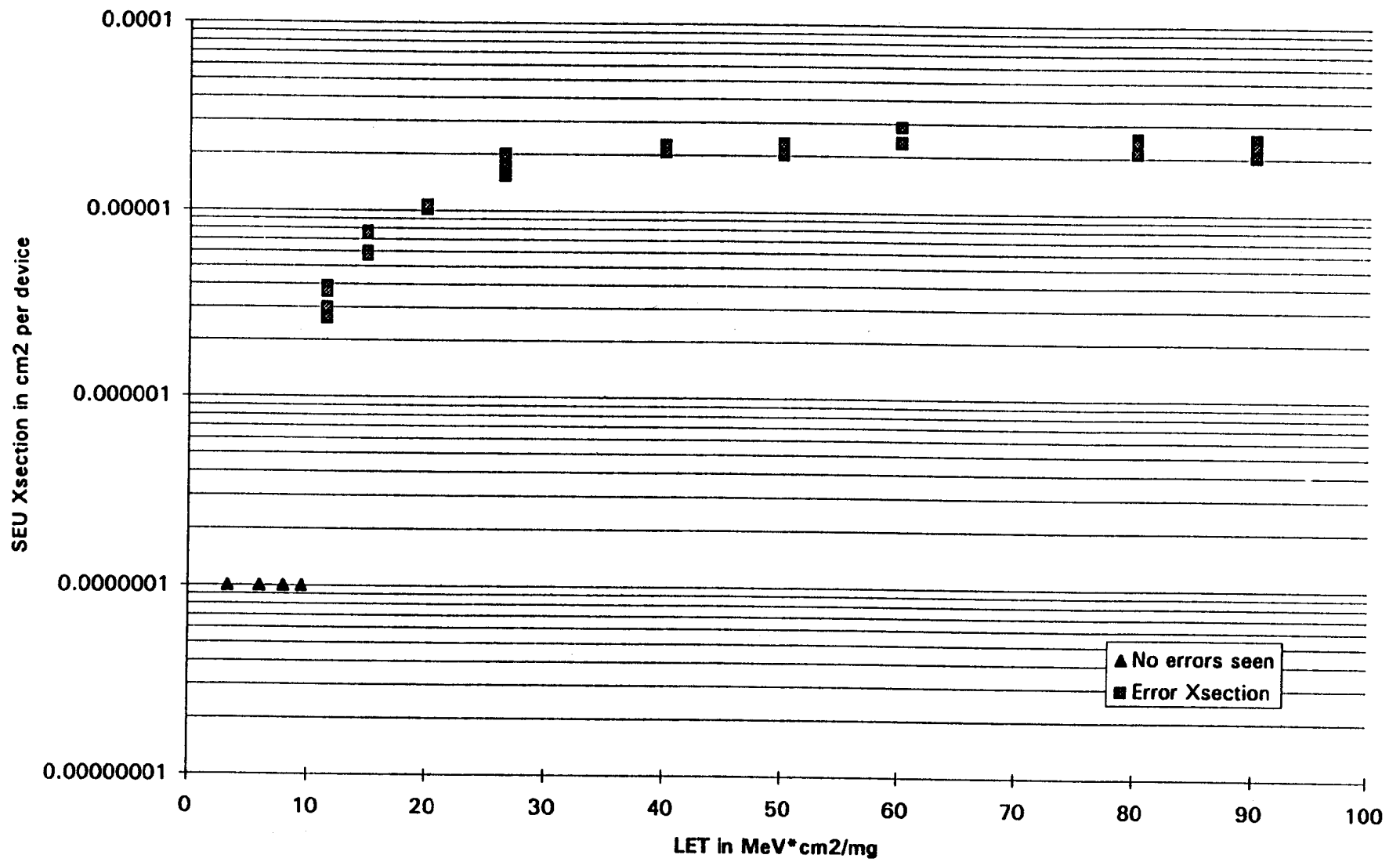
- ☐ Key Parameters for parts: LET threshold (LET_{th}) and saturation cross section (experimentally determined parameters).
 - ☐ LET_{th} is sometimes defined differently by different test groups. Examples can be: taking the LET value at 10 % or 1% of the saturation cross section.
 - ☐ This can be orders of magnitude different than the JEDEC recommended definition: the minimum LET value that causes an effect to the device at a particle fluence of 1E7 per cm².
 - ☐ Cross-section is defined during ground experimentation as: cross-section in cm² = N SEUs / F Particles/cm².
 - ☐ An LET_{th} over 35 is good, under 15 may have potential proton effects as well.
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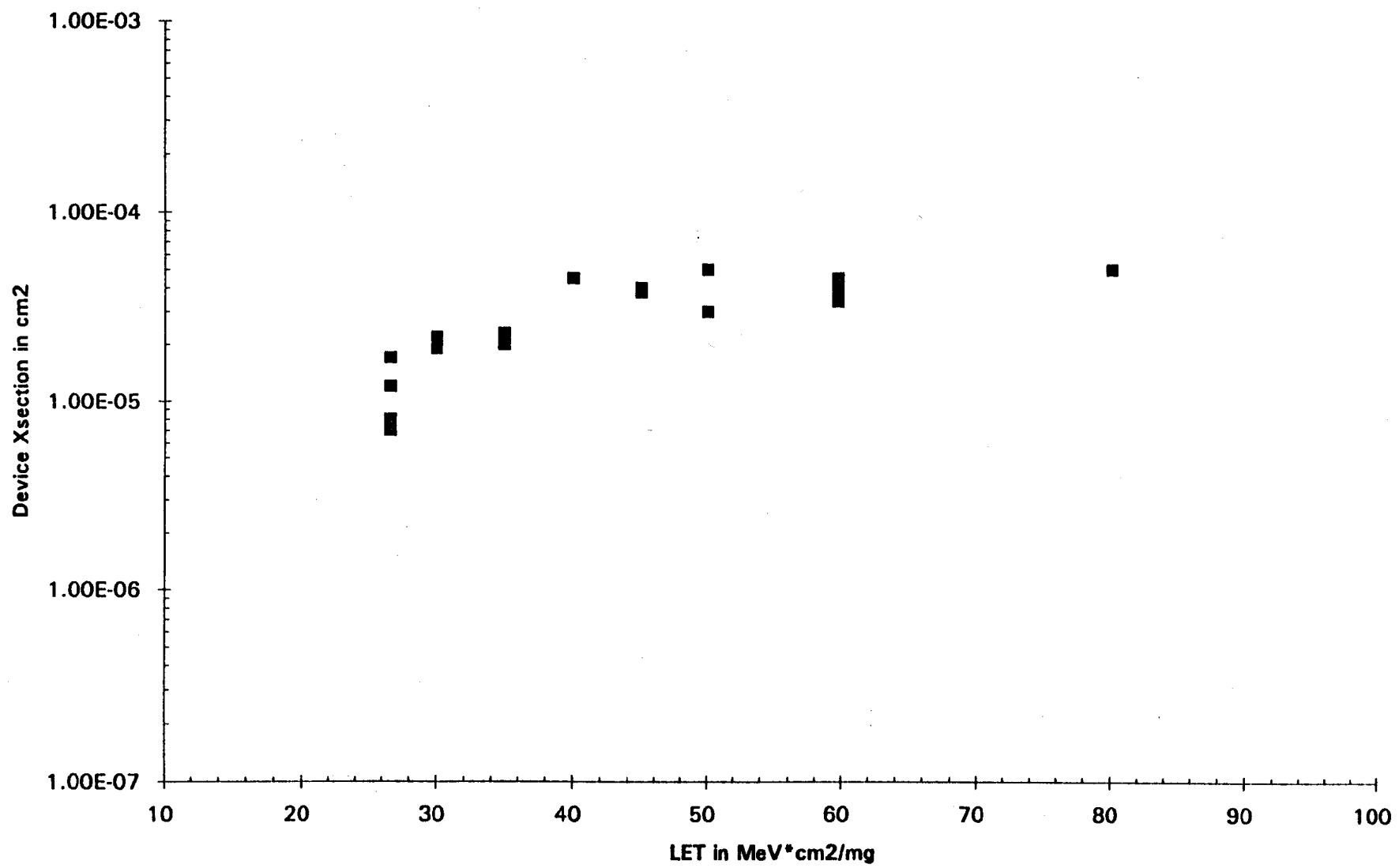
How SEU heavy ion testing should be performed - Mission-specific testing (1)

- ☐ Many devices have variable SEU sensitivities based on how they are going to be used
 - ☐ Examples: clock rate, data pattern, operating mode, voltage levels
 - ☐ Test setup should exercise device in a manner that simulates how it may be used in flight
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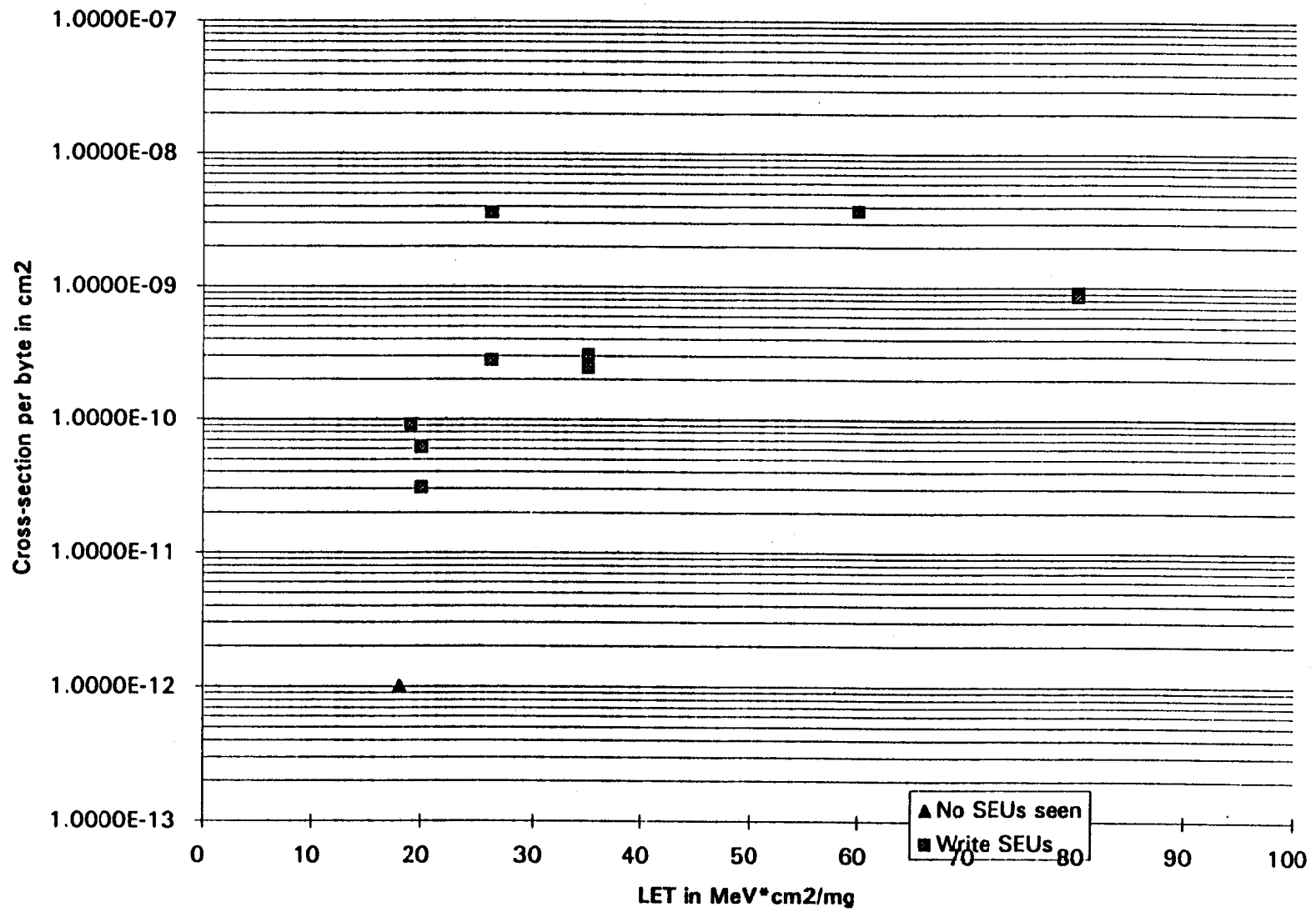
ATMEL 22V10 PAL Error Cross-section



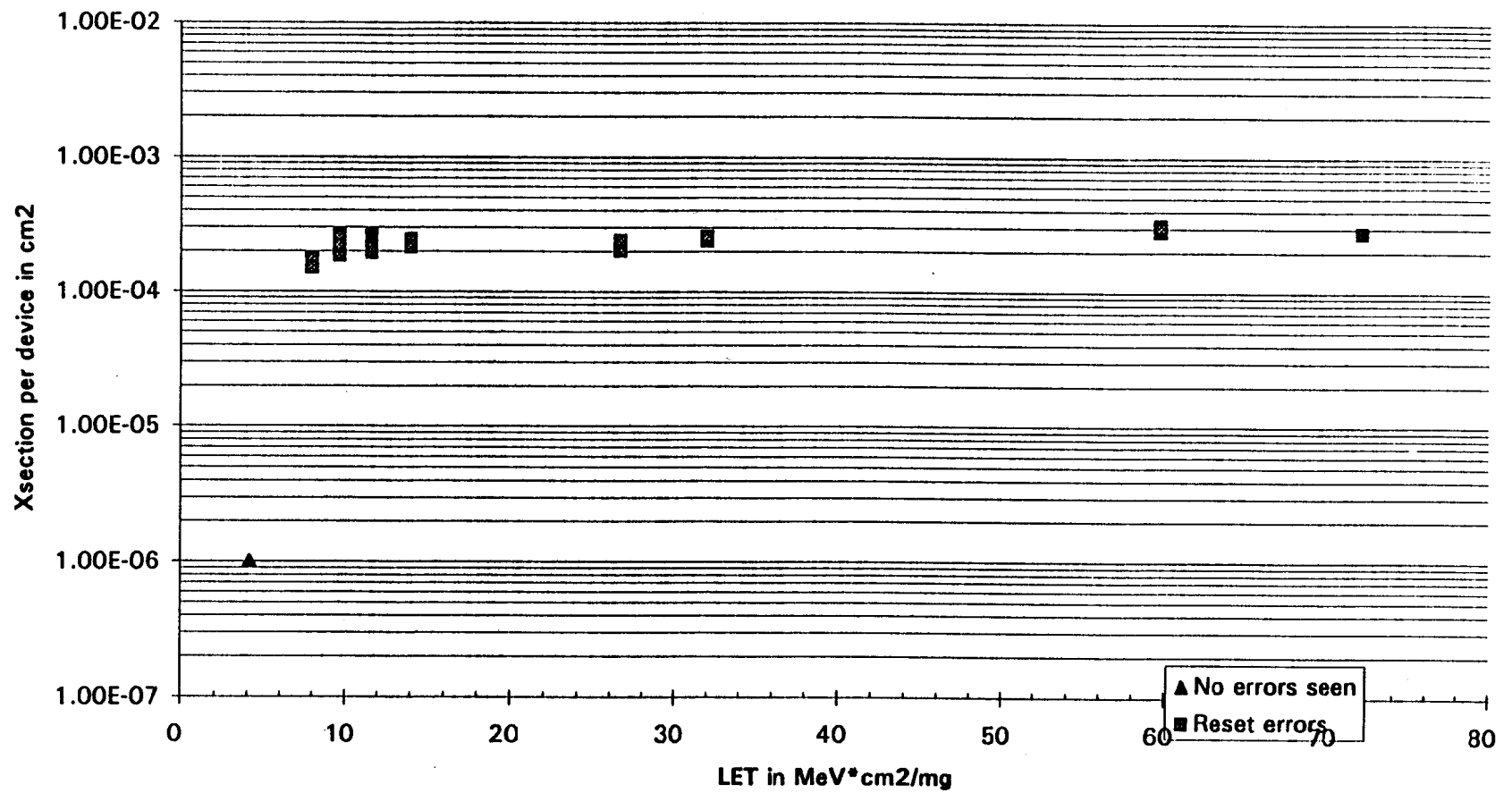
IDT49C460 Total Errors Xsection



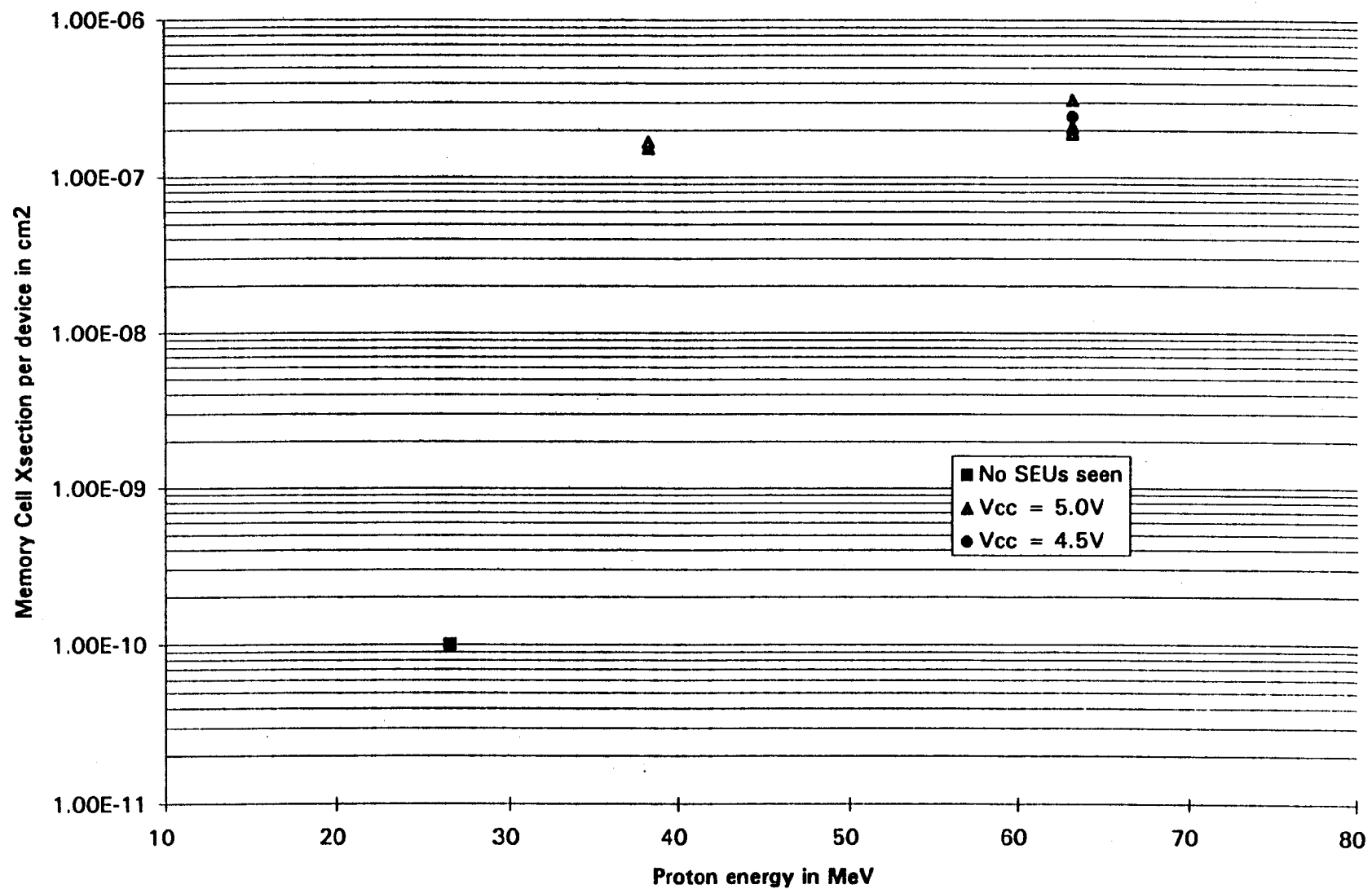
HM58C1001 EEPROM Write Errors - Byte Mode



Modular Devices 2690R DC-DC Converter "Reset" Xsection



Hitachi DRAM Memory Cell Proton SEU - Dynamic Mode



Figure

V. SUMMARY

The findings of these tests are interpreted in the following.

- We typically divide SEE test results into the following four categories.
Category 1 - Recommended for usage in all spaceflight applications.
Category 2 - Recommended for usage in spaceflight applications, but may require *some* SEE mitigation techniques.
Category 3 - Recommended for usage in some spaceflight applications, but requires *extensive* SEE mitigation techniques or SEL recovery mode..
Category 4 - Not recommended for usage in any spaceflight applications.
- Category 3 devices for this test trip are:
All the 80386 and 80387 devices tested.
- Category 4 devices for this test trip are:
All the 82380 devices. They *may* be used but require very extensive SEU and SEL mitigation.



SEU Mitigation Examples - memories and data streams (1)

- ☐ Parity check
 - ☐ Counts the number of ones in a memory address or data stream
 - ☐ May be even or odd
 - ☐ Only detects if wrong number of ones exist. Does NOT detect which bit(s) or any method of correcting
 - ☐ Can be done in H/W or S/W
 - ☐ Example is a 512x9 FIFO. Use first 8 bits as data, ninth as parity bit.
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SEU Mitigation Examples - memories and data streams (2)

- ☐ Hamming Code
 - ☐ Simple block error code that detects the position of a single error and the existence of more than one error
 - ☐ Normally described as single bit correct, double bit detect.
 - ☐ Can be done in H/W (usual method) or S/W
 - ☐ Example: 72-bit data path has 8 bits added for Hamming code (i.e., a 80-bit wide path with overhead)
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SEU Mitigation Examples - memories and data streams (3)

- ☐ Other Block Codes
 - ☐ BCH
 - ☐ Moderately powerful encoding scheme capable of detecting multiple errors in a data path
 - ☐ Example: (1023, 993, 3) = 993 bits of data, 30 bits of code (overhead) capable of correcting up to 3 bits in error.
 - ☐ Reed-Solomon
 - ☐ Very powerful encoding scheme able to detect and correct consecutive and multiple errors in a data path
 - ☐ Example: (255,223) = 223 bytes of data, 32 bytes of overhead with the ability to correct 16 consecutive bytes in error. This particular example is using NASA VLSI Design Center's rad-hard encoder.
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SEU Mitigation Examples - memories and data streams (4)

- ☐ Convolutional encoding
 - ☐ Differ from block coding by interleaving check bits continuously in the data stream
 - ☐ Good for mitigating isolated burst noise. An example is threshold decoding where 4 consecutive bits can be corrected assuming the next 8 bits are error free
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SEU Mitigation Examples - memories and data streams (5)

- ☐ System level protocol
 - ☐ Best description is by example: MIL-STD-1773 Fiber Optic Data Bus
 - ☐ Overtop of the physical layer of hardware is a standard protocol. Several error detection schemes are implemented including: parity (described earlier) and non-valid Manchester encoding.
 - ☐ The standard protocol has an option to retransmit (retry) 1773 bus transactions if they fail (up to three times is possible).
 - ☐ Thus, the error detection is via normal methods, while the correction is via retransmission.
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SEU Mitigation Examples - Other H/W and systems

- ☐ Watchdog timers
 - ☐ Can be implemented at multiple levels: subsystem-to-subsystem, box-to-box, board-to-board, device-to-device, etc...
 - ☐ Can be implemented using hardware, software, or a combination thereof.
 - ☐ Typically thought of as an "I'm okay" method:
 - ☐ Example 1: Device A has to say "I'm okay" to an independent device B(timer, interrupt controller,...) on a periodic basis. If A fails to do so within an allocated time period, device B initiates an action (soft reset, power reset, power removal, switch to redundant unit, safhold, telemetry, command, etc...)
 - ☐ Example 2: Passive timeout. If no uplink is received in some timeframe, reset to the receiver may take place.
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SEU Mitigation Examples - Other H/W and systems

- ☐ Redundancy (warm or cold spare)
 - ☐ Backup devices/boxes/systems that sometimes have cross-strapping so no performance hit occurs.
 - ☐ Example: MIL-STD-1773 is fully redundant with an A side and a B side. If a 1773 bus transaction fails on bus A, there is the option of retrying on the B bus.
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SEU Mitigation Examples - Other H/W and systems

- ☐ Lockstep systems
 - ☐ Two circuits/systems running synchronously. If their outputs do not agree, an error has potentially occurred. Reset, command, etc....
 - ☐ Voting schemes
 - ☐ Three or more systems providing a response. Pick the answer that corresponds to two.
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Examples of System Compensation for SEE

Solid State Recorders

- Utilizes single bit error correction, double bit detection (EDAC)
- No lost data for TONGUE/Adstar-3 (launched 8/91) or SAMPEX (launched 7/92)
- Devices characterized for SEP prior to flight

SEDS MIL-STD-1773 Fiber

- Optic Data Bus
- Utilizes 1773 protocol error detection as well as automatic message retries
- Fully Successful operation including a large solar flare time period
- Devices thoroughly characterized and modelled prior to flight



GSFC resources available

- Goddard has many resources to aid designers including:
 - BG Stassinopoulos, Radiation Physics Office, 220-3114 (Environment and physics properties)
 - Ken LaBel, Radiation Effects and Analysis Section, x6-9936 (SEU testing, circuit design, parts performance)
 - Kusum Sahu, Paramax - Code 311, 731-8954 (TID testing, parts selection)
- Note: testing varies greatly in price depending on complexity and urgency of work
- Databases of parts
 - Kusum and Ken at GSFC, JPL Radatabank (<http://keyvan.jpl.nasa.gov>), DNA's DASIAC (ERRIC), NRL's REDEX



Hot topics

- Linear bipolar devices failing at low dose rates (and doses)
- Processors and memories
- FPGAs, power converters
- Radiation mitigation (as opposed to rad hard devices). Closing of rad hard foundries
- MPTB: Microelectronics and Photonics TestBed. DoD-sponsored radiation experiment



Radiation effects and analysis home page

- <http://flick.gsfc.nasa.gov/radhome.htm>
- on-line environmental overview, test data, flight data, experiments, etc...

